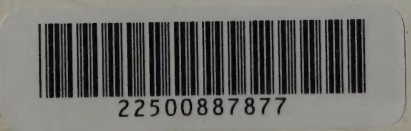
# THE BOYLE LECTURE

FOR

1905

# *THE CEREBELLUM*

VICTOR HORSLEY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(*Copy of the frontispiece of Boyle's works, folio edition,* 1744.)

# THE CEREBELLUM:

## *Its Relation to Spatial Orientation and to Locomotion*

BEING THE

## BOYLE LECTURE FOR 1905

Delivered before the Junior Scientific Society of the University of Oxford
HAROLD SAVAGE, Esq., President, in the Chair

BY

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London
JOHN BALE, SONS & DANIELSSON, LTD.
OXFORD HOUSE
83-91, GREAT TITCHFIELD STREET, OXFORD STREET, W.

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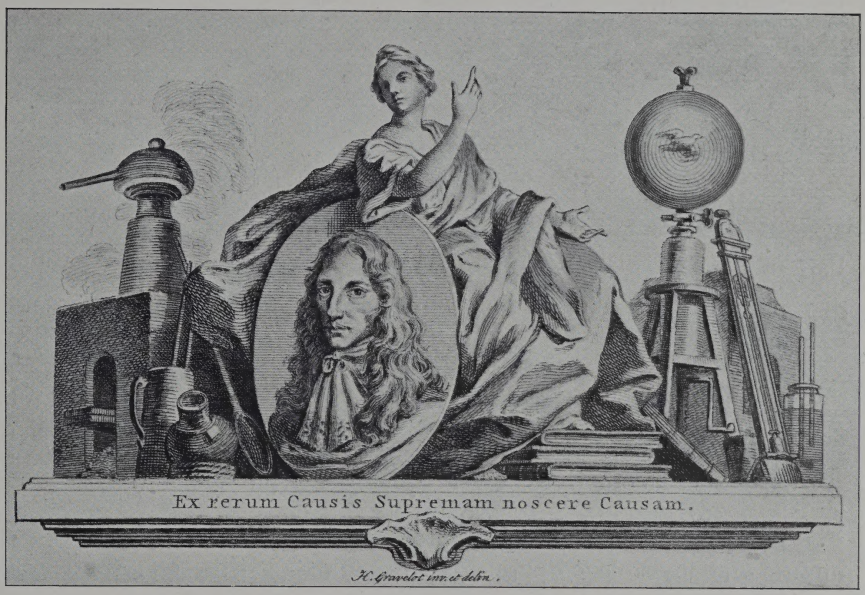


*(From the title page of Boyle's works, folio edition, 1744.)*

Robert Boyle, philosopher and cogitator, was a singularly interesting figure in physical science, because whilst a physicist he was yet intimately associated with that remarkable Oxford School of Medicine of the 17th Century to which we owe so much. His friendship with the great Dr. Willis, and that anatomist's most able assistant, Dr. Lower, led Boyle, as we shall see, to consider physiological problems from a physical and not a vitalistic point of view.

Nothing is more instructive in the history of Medicine than a comparison between the progressive and illuminating use of physical interpretations of biological phenomena and the confused and often absurd statements of vitalists, conveyed as they necessarily are in

words which can only bear relation to so-called material processes and things.

This striking difference from so many 17th Century writers finds abundant illustration in the letters of Boyle and his friends. Let me now select a couple of passages which directly apply to the present subject. Thus Boyle in his Paper entitled "The Second "Part of the Christian Virtuoso," says: "We cannot think it strange "that our anatomists should judge the brain to be the principal source "of motion, or, as learned men are wont to express it, the seat of "the locomotive faculty."

And further :—

"For the locomotive power alone may suffice to challenge our "wonder! Since philosophers themselves may justly admire that such "minute and invisible corpuscles as the animal spirits, and those, too, "in no greater numbers than can be furnished by and contained in "the brain and inconspicuous cavities of the nerves, even supposing "those parts assisted by some small portion of liquor to make explo-"sions,* should be able to move all the outward limbs and internal "muscles of the body in such various manners and with so much "agility and strength, as we see they do in divers lusty and active "men, and more particularly in some dancers on the ropes here among "us who themselves are far exceeded in nimbleness and sprightliness "by several of the same profession in the East Indies, as not only "credible authors inform us in their printed voyages, but most credible "eye-witnesses of our own nation now alive have assured me."

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* It must be remembered that the Galenical views of animal spirits prevailed to the 17th Century, and Willis speaks of the brain containing the "spirits." The primal idea was that the ventricles were the seat of their development. Hence the presumed importance of the cerebro-spinal fluid or "liquor."

It is the purpose of the present lecture to show how the current views in Boyle's time of the mode in which the nervous system provides for our equilibrium and locomotion compare with those of the present day, and it will then appear how soundly based are all statements which rest on the sure foundation of physical observation. We have therefore to find out what Boyle's friends told him was the nervous mechanism of balancing in space, by which people were able, especially "in the East Indies," to dance with such extreme ability on a tight rope.

After all, there is nothing more wonderful or "admirable," to use Boyle's expression, in a person preserving his equilibrium while walking on a rope than on a road, for in both cases he is translating his body through space, his brain is, to use Willis's term, involuntarily recording his orientation, *i.e.*, is automatically holding his body erect.

The precise question to be answered is, What part of the central nervous system is issuing the requisite orders to the limbs and trunk muscles to contract and hold up the body, what parts of the brain recognise the success or non-success of the balance obtained by those muscles, and what part of the brain notes, judges and remembers the actual position of the body in space?

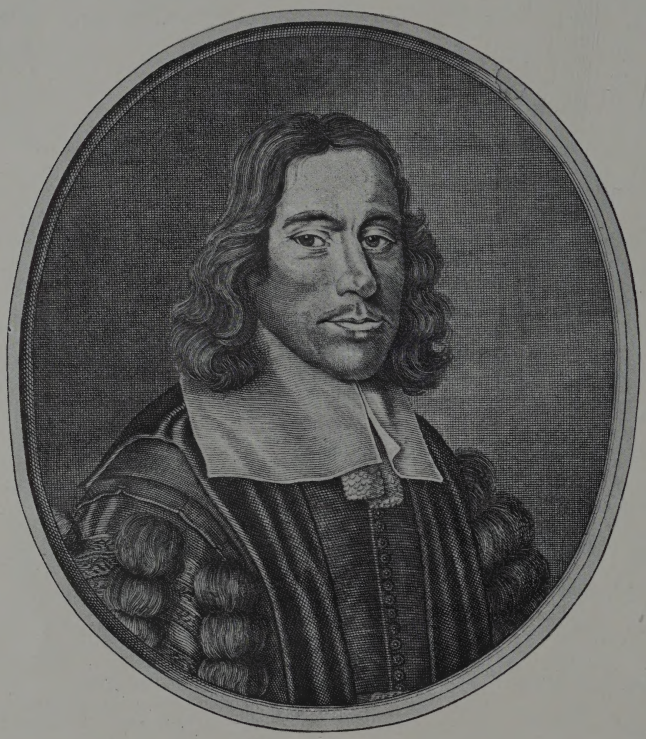
Let me say at once that it is the surface or cortex of the great brain or cerebral hemisphere which consciously appreciates and records our position in space, while it is the cerebellum which to a large extent preserves our equilibrium, guides our locomotion and assists in the regulation of our finer movements.

This is our present-day view.

It was amply anticipated in the middle of the 17th Century by Willis.

This great man, working and discoursing in his rooms in Canterbury quadrangle of Christ Church, in 1660, with his friend Lower the anatomist and Wren the geometrician, astronomer, and architect, most particularly describes in the preface to his work on the anatomy

FIG. 1.



THOMAS WILLIS.

*Copy of the contemporary portrait which is the frontispiece to his "Opera Omnia," published at Amsterdam,* 1682.

of the brain his indebtedness to Lower for so skilfully dissecting his preparations, and to Wren for most of the illustrations which adorn the work. Sir Christopher Wren himself was keenly interested in physiology, anatomy and medicine. He undoubtedly invented transfusion, and there seems to be no doubt that Sprat, the 17th Century

historian of the Royal Society, was correct when exposing the way in which Wren was plagiarised, he stated that :—" He was the " first Author of the noble Anatomical experiment of injecting Liquors " into the Veins of Animals. An Experiment now vulgarly known but " long since exhibited to the Meetings at Oxford, and thence carried " by some Germans and published abroad."

Lower was a very original thinker, and no doubt an invaluable assistant to such a man as Willis ; he, too, worked in Christ Church, but was expelled, as he tells Boyle in one of his letters, from that College because he would not take orders. Another of his exceedingly interesting letters to Boyle very correctly gives the state of knowledge in Oxford at the Restoration on the subject of the cerebellum, as follows :—

" Letter from Dr. Lower to Mr. Boyle.

" Christ Church, Oxford,

" *January* 18, 1661.

" Honoured Sir,

" I received your letter, and should have wrote to you sooner but that the doctor " (that is, Dr. Willis) " was not at leisure till of late to make those dissections of the brain, which he hoped ; but at length we have had the opportunity of cutting up several, and the doctor, finding most parts of the brain imperfectly described, intends to make a whole new draught thereof, with the several uses of the distinct parts, according to his own fancy, seeing few authors speak any thing considerable of it ; so that at present I shall suspend my thoughts which I had of sending you a relation of the discourse we had in the several dissections, and only tell you that, according to his opinion of the use of the cerebellum for involuntary motion, he shewed me several times the nerves (which authors call the sixth

conjugation) to proceed out of a stalk or stem, which comes down out of the cerebellum, and makes a great half circle under the medulla oblongata, and so returns and ends in that nerve, on each side; which half circle is clearly distinct from the medulla oblongata, by comparing

FIG. 2.

RICHARD LOWER, 1631-1691.
*Copy of the portrait reproduced in Prof. Stirling's "Some Apostles of Physiology,"* 1902.

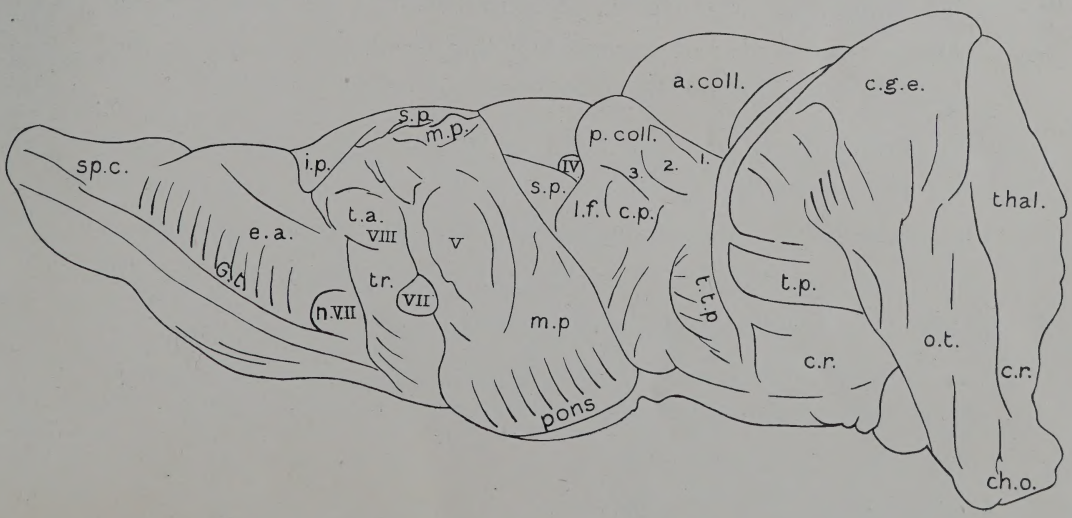
the several texture and position of their fibres, as well as their outward line and figure; so that one may very well conceive that circle to serve for a distinct and particular use, and to differ from the medulla oblongata, as well as to conceive the spinal marrow, with the

medulla oblongata, to be really distinct organs (which is certain from palsies of half the body), and yet they are not thoroughly divided,

Fig. 3.

Bulb and Mesencephalon of Sheep (*Ovis aries*). $\frac{2}{1}$.
*(Photograph of an old specimen in the Radcliffe Museum, Oxford.)*

The cerebrum and cerebellum have both been cut away from the brain stem. The cut through the cerebellar stem is the surface marked i p, sp, mp.



a. coll. Colliculus anterior vel corpus quadrigeminum anterius.
p. coll. Colliculus posterior vel corpus quadrigeminum posterius.
c. g. i. Corpus geniculatum internum vel mediale.
c. g. e. Corpus geniculatum externum.
o. t. Tractus opticus.
thal. Thalamus.
cr. cr. Crus cerebri (containing outgoing cerebral paths for "voluntary" movement).
ch. o. Chiasma optica.
t. p. Temporo-pontine bundle of Turck.
c. p. Corpus parabigeminum vel eminentiæ mesencephali laterales Retzii.
1 Palliotectal fibres, dorsal bundle
2 Tectogeniculate bundle
3 Palliotectal fibres, ventral bundle or brachium postremum Retzii.
} Brachium posterius.
l. f. Lemniscus lateralis.
s. p. Pedunculus cerebelli superior.
iv. Nervus trochlearis.
v. Nervus trigeminus.
vii. Nervus facialis.
viii. Nervus auditorius et vestibularis.
t. a. Tuberculum acusticum.
m. p. Pedunculus cerebelli medialis (the great half circle of Willis) or pons varolii.
i. p. Pedunculus cerebelli inferior.
n. vii. Nucleus of facial nerve.
e. a. External arcuate fibres.
G. t. Tractus spino-cerebellaris ventralis of Gowers.
tr. Trapezium (the lesser half circle of Willis).
sp. c. Spinal cord.

but only superficially along the middle. The auditory nerves also, which lie next behind the other, and go into the os petrosum on each side of the skull, seem to arise out of another ring, though less than the former; into which ring descends also that stem out of the cerebellum. And *Varolius* formerly affirmed, that the auditory nerves came out of the cerebellum. The doctor likewise observed the cerebellum to be distinguished into two medullary parts, the middle part (which being cut, does so elegantly resemble a tree with branches) being as it were the pars corticalis dividing between the two medullary parts, for what use you may hereafter hear."*

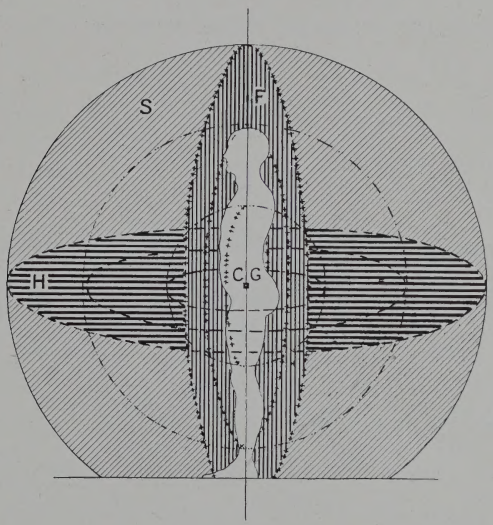
Hence Willis's idea or fancy, as he called it, suggested to him that the cerebellum was an organ for the execution of involuntary or automatic actions and movements, that the pontal and trapezial fibres were a cerebellar rather than a cerebral system, and that the latter ran through the medulla oblongata.

* Unfortunately, Dr. Lower's gift of writing seems to have been not unlike that of the modern *feuilleton* author, for he breaks off his description of Willis's views at this exciting point.

(Willis made the very natural mistake of including too much in his catalogue of functions of the cerebellum, for instance, he names the automatic rhythmical movements of respiration and circulation which we now know can continue when the cerebellum has been wholly removed.)

To quote his own expression the cerebellum is an "Urbs regiminis animalis," and pursuing this metaphor he said that nerve tracts lead

Fig. 4.




S. = Sagittal plane. F. = Frontal plane. H. = Horizontal plane.
C.G. Centre of gravity of the whole body.

from the cerebrum or great brain as from a "metropolis" to the cerebellum.

To now consider how the Cerebellum is the seat of representation of many useful automatic movements we must clearly understand by what means we preserve our equilibrium and how we are able to move about in space.

Perhaps to clear the ground it will be better to consider for a moment how we are conscious at all of the space surrounding

our bodies and of the points or objects, that is to say localities, in each of the three chief planes of such space (see Fig. 4).

How do we record our knowledge of space? How do we know of space and how do we remember what we learn of it? The answer to all these questions is of course that our senses are the avenues to our knowledge of space, and that as avenues they exhibit remarkable differences of degree of efficiency.

The well-known "five" senses may be taken in the following order, and to that list must be added a sixth sense, that of special orientation:—

I. Sight.

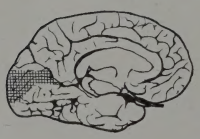
II. Hearing.

III. Smell.

IV. Taste.

V. Touch (which for the purpose of the present paper must of course include the muscular and arthrodial sense, topognosis,* stereognosis, the temperature sense and pain sense.

VI. Special orientation.



(I.) *By Sight.*—The facts obtained by the extraordinary penetration (*i.e.*, range of distance) and minute accuracy of detail which characterise vision are registered in the calcarine region of the occipital lobes and possibly also in the occipito-temporal region of the cortex of the great brain.

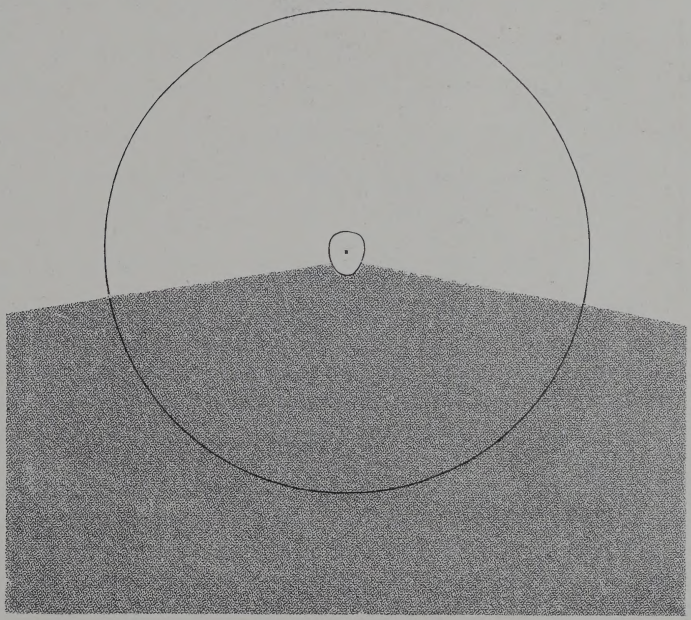
At the same time the topographic limitations of the function of

* By the term topognosis I distinguish the knowledge of points on the surface of the body as far as their precise position in space is perceived by the kinæsthetic cerebral cortex as at any rate the first pallial receptive station. Whether or no that station is the post-central æsthetic area of Mills, Dana and Campbell cannot here be discussed (see below page 25).

vision are very arbitrary, and, as shown in Figures 5 and 6, when the visual axes are parallel to each other, to the horizon and to the mesial plane of the body, we know nothing from sight of what is under our feet or at our sides, or behind us or overhead. Conse-

FIG. 5.

SIGHT.



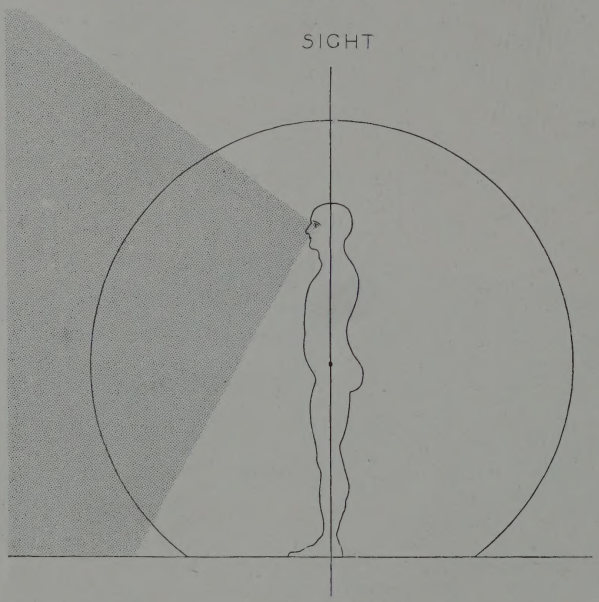
The central point is the longitudinal axis of the body and the line surrounding it is the outline of the head viewed from above. The shaded area in front of the face gives the lateral limitations of the visual field and shows that this does not reach the fronto-medial plane of the body.

quently our completer knowledge of circumferential space obtained by sight is only gained by turning the head and also the eyes.

So almost at once we are compelled in our investigation of our orientation in space to mention a necessary concurrent "locomotion" (Boyle) of part of the body, viz., the head and eyes. We shall

gradually see how important is this general question of the dependence of orientation on motion and on this movement in particular, and further how directly it concerns the cerebellar function, but I may point out to you that man has obtained the said rotation movement of the eyes and head as a fundamental part of his orientative faculty by a phylogenetic process, for if we take as typical examples of that

FIG. 6.




In this diagram the upper and lower limitations of the visual field are shown when the optic axes are horizontal. It is important to note, however, that as can be easily shown by observing an object advancing horizontally from behind that the upper limit is determined by the orbital margin, whereas the lower is entirely dependent on the sensitiveness and position of the ora serrata.

minority of animals who have their eyes arranged for consensual visual fields the owl, the macacque (rhesus) monkey, and man, we see the ascending scale of evolution of this faculty as follows :—

The *owl* turns the head towards a direction of sound, and so completely and rapidly that it occasionally turns the facial surface

through 180° so as to look straight over its back. The *monkey* turns its head and to a less degree its eyes, while in *man* the turning of the eyes is earlier than the rotation of the head.

To return to our estimate of space by our eyes, of course in all balancing of the body we desire to know how far we are advancing or bending, and we effect such judgments partly* with the help of vision, not with real accuracy fortunately, or there would be no Test Matches. It is commonly said we visually estimate the position of points in space by converging the axes of the eyes, and obtaining by the muscular sense of the extrinsic ocular muscles an idea of the degree of movement, gain thereby an appreciable idea of the propinquity or reverse of any object.

But such movements of the visual axes are only a very small part of the function, for persons who have the misfortune to lose an eye can acquire this power of judging distance, and though endowed with only monocular vision, yet gauge the position in space of any given object with quite reasonable accuracy. Besides, if we really depended on the motion of the eyeballs in judging distance it would be a function of great phylogenetic antiquity, and early exhibited but as a fact children take a long time to acquire this faculty, and only do so in proportion as their powers of locomotion and of muscular and arthrodial sense develop. The real truth, I submit, is that we depend essentially upon "locomotion" to learn the details of space, and it is by translation of our bodies and limbs that we experience and remember the depths and distances which separate us from any definite point in any plane of the space surrounding us. A good proof that transference is the real source of our education in perception of spatial depth is afforded by the cases of persons who, blind from

* Chiefly by the sense of special orientation (semicircular canals, see page 31).

birth, have by a successful operation had the power of sight conferred upon them. These individuals, while blind, have their knowledge of depth limited by the length of the limbs, and consequently, immediately after the operation think that every point they see in surrounding space is on a plane a short distance in front of their body surface.

This is, as will be seen directly, precisely the scope of our spatial knowledge when we rely on touch as the only sense giving us information.

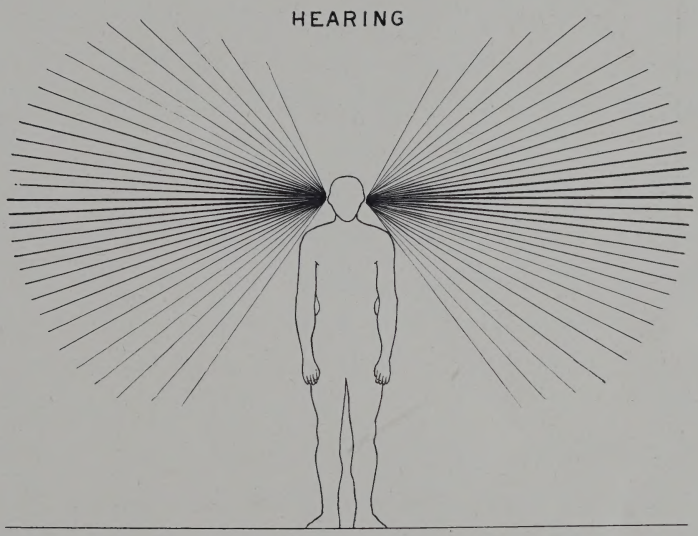
In monocular vision a certain degree of information may follow from changes of accommodation, but this must be extremely small compared to our experience of translation and locomotion.

To sum up so far, then, our knowledge of where we are in space, is largely derived from our sight sense, but to exercise it adequately we are obliged to turn our eyes, head, and more rarely the body around the chief spatial axes and to translate our bodies from point to point by means of our limbs. As regards the provision for these functions, the co-ordinated muscular arrangement for rotation of the head and eyes (which while we are awake and active is incessantly performed) is most represented in the ponto-cerebellar centres, but the general locomotion of the body in the cerebro-spinal apparatus.

II. *By Hearing*.—The sense of hearing ranks next to sight on account of its appreciation of depth, *i.e.*, spatial distance in recognition of position, and of course by means of our sense of hearing we are aware of points in surrounding planes, but our knowledge of the precise locality of such points is very poor, and this is not only true of man, but also of the lower genera; even in the dog, where, as may often be seen, the animal when whistled to, stops and turns his head about trying to determine the direction and source of the sound.

I roughly showed this to be the case a number of years ago, but the matter is now being thoroughly considered by the Wilde Reader in Psychology of this University. Figure 7 sufficiently indicates that it is the frontal or transverse planes which are best known to us by audition, the optimum being that passing through the auditory meati. Now as to the question, Where in the brain do we record the results of this localising by hearing? there is no doubt that the temporal

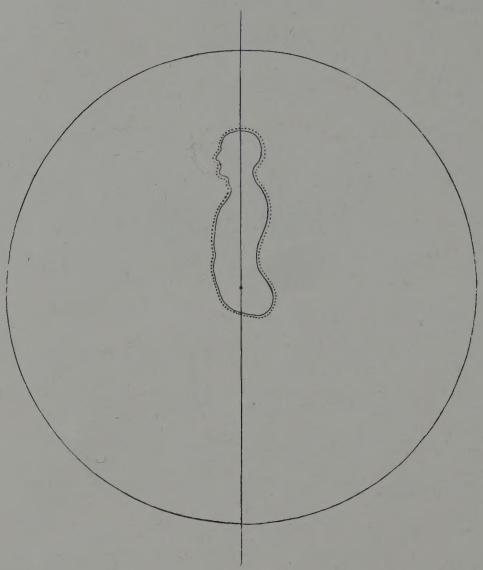
FIG. 7.




cerebral cortex must be the seat of this auditory orientation knowledge. We shall presently come back to this same part in our search for the localisation of the cerebral representation of the vestibular nerve, the source of special orientation, not forgetting too that the attitude of conscious attention to audition, *i.e.*, when the head is held on one side, is in fact what is clinically known as the "cerebellar attitude" of the head, and is the functional duty of the dentate nuclei of the cerebellum according to the observations of Dr. Clarke and myself.

III. *By Smell*, and IV. *By Taste*.—We need spend little time on these senses as among our guides to topographical knowledge. We owe little to our olfaction, and use it but little for finding our way about, because the diffusibility of odours is so great that their localisation in space is correspondingly difficult. The sense of taste is even far less significant, being a contact sense limited to a small area of internal

FIG. 8.




To show that in the absence of limbs, and therefore locomotion, our only knowledge of space gained by touch would be a layer in direct contact with the body surface as shown by the dotted line.

mucous membrane. At the same time, it is not uninteresting to remember that these senses are also represented in the temporal lobe of the cerebrum (the pallial organ of orientation *par excellence*), on its mesial aspect.

V. *By Touch*.—For our "locomotion," whether of legs, or arms, or head, the sense of touch is of the greatest importance, and above all,

for the elucidation of the functions of the cerebellum. I must therefore now ask your attention to the circumstances under which we rely on our sense of touch to (1) preserve our equilibrium, and (2) to move the head, trunk, and limbs in a profitable, *i.e.*, co-ordinated manner.

Take the question of contact of the whole body. This clearly must be limited according to whether we include the exploratory capability of the limbs or not.

If we exclude the limbs, then, we see (Figure 8) that, apart from being conveyed here and there by locomotion, and so coming into contact with fresh planes of space, the surface skin of the body can only know the plane of absolute contact.

Owing, however, to the mobility of our limbs, we really know a good deal about the space immediately surrounding us, say two feet deep in front and half a foot to one and a-half feet behind (Figures 9 and 10), while of this elliptical shell it is probably the central anterior third of which we know most, especially along oblique planes towards the mouth and face.

We have already seen that persons who suddenly obtain vision after being continuously blind from birth have no knowledge of spatial depth other than the limited shell of space now referred to. The interesting converse position is that in which people are suddenly blinded, *e.g.*, by accident, or when blindfolded. It is seen then that the attitude they assume (Figure 11), is such as will enable them to explore the utmost limits of this shell of space, for they incline the body and reach the arms out as far as possible so that the sensitive tips of the fingers should explore the concave surface, as it were, of the circumferential shell in which they find themselves. This conscious attempt to project as far as possible the

FIG. 9.

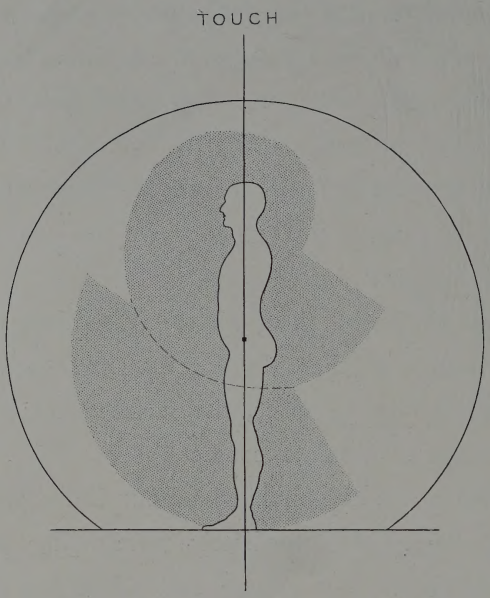
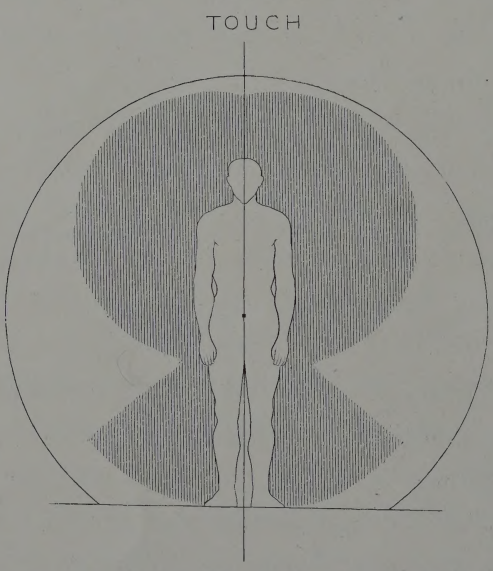



FIG. 10.




The shaded areas represent the amount of space which can be explored by the limbs when the longitudinal axis is vertical.

power of appreciating the sense of touch, is also shown by the blind man employing a stick for purposes of exploration, and further, by the fact that when we irritate one of our nerve trunks in its continuity, *e.g.*, the "funny bone," or ulnar nerve, we project our consciousness of the irritation of the fibres which have come from the little finger

FIG. 11.

The principal figure in Wilkie's picture of the "Game of Blindman's Buff."

as far as the finger-tip itself, which we declare to be the seat of "pins and needles." It is reasonable, therefore, to assume that we are always endeavouring to improve our record of our position in space, that we are very frequently subconsciously aware of the great

limitation of our power of exploration, and hence we endeavour to extend our spatial diameters as far as we possibly can. For the same reason we know progressively less and less of space as we proceed from the body outwards, and thus arises a source of error in our spatial knowledge which I venture to call the error of propinquity, because our misjudgments are as to the actual nearness of points surrounding us.

It further follows that if we commit this error it is more likely to be that we think an object to be nearer than it really is.*

May I mention a clinical fact bearing on this error of perception, though it perhaps bears more on our sensorial and memorial basis of consciousness than of equilibrial co-ordination. It is this: I have found in all my cases of high amputation (an operation the increasing rarity of which is one of the innumerable benefits we owe to Lord Lister) that the well-known subjective delusion of the hand or foot being still attached to the body is always accompanied by this error of propinquity. Thus I find that practically the imaginary hand is believed by the patient to be in the circumferential plane just below the middle of the forearm, and the foot in that just below the middle of the leg.

Our memory of the space surrounding us, so far as it rests on the basis of the exploratory movements of our hands, feet and limbs, finds its physical localisation in the so-called "motor-area," or, as we ought to call it, following Dr. Bastian, the kinæsthetic area, and where, as Hitzig, and, after him, Munk, have specially taught us, the memories of movements are recorded.

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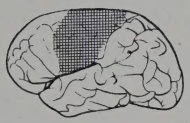
* While this paper is passing through the press, Dr. Slinger has shown by the plate method (see p. 26) that this error of propinquity is normally predominant as compared to distality in our localisation in space.

This in man is primarily the ascending frontal gyrus, the posterior third of the second and a portion of the third frontal gyrus.

I showed, nineteen years ago, that when this area was attacked destructively by disease the blindfolded patient, though he could name correctly the corresponding part of the surface of the body that might



be touched, was nevertheless quite unable to indicate with his other hand accurately the point touched, and, further, that his topognostic error was in the case of the upper limb, such that his indication of the spot was always proximal, *i.e.*, too near the trunk, and, finally, that this error increased directly with the increase in the area of kinæsthetic cortex* destroyed.

The probable error of nearness or propinquity therefore should be the first to be recognised among the conditions affecting our knowledge of the position of our limbs, and, above all, of our hands in space.

So far, however, we have not directly considered the influence which the cerebellum exerts on the movements of the upper limbs thus engaged in the exploration of space. Now, clinically we have known for a long time that one of the most valuable signs of cerebellar tumour is the loss of power to carry the hand towards any definite point in a co-ordinate manner ; thus, for instance, the patient cannot, when asked, touch the tip of the nose correctly with the forefinger, if his eyes are closed. I have long thought that this particular sense power, which is clearly dependent in part on the cerebellum, should be

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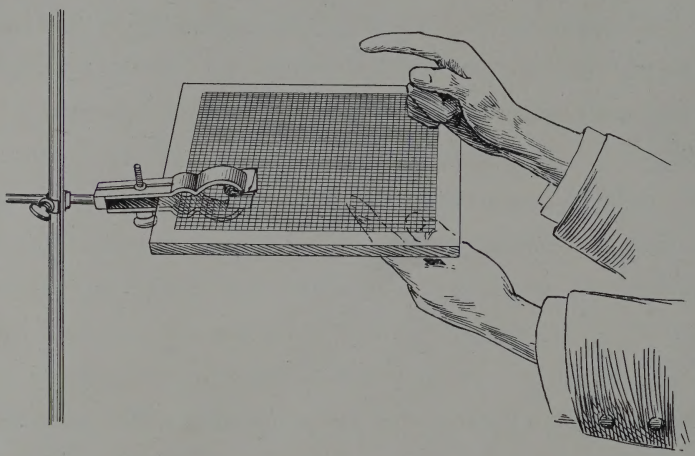
* It must not be forgotten that the pallial representation of stereognosis is localised by Mills, Dana, and Campbell in the post central region, *i.e.*, immediately behind the kinæsthetic area.

investigated in relation to the three planes of space, assuming the body to stand in what is called the anatomical position with the visual axes horizontal. It is but quite recently, however, that I have been able to give attention to the subject, and can, therefore, only indicate what is the approximate error in normal persons compared with that seen in people the victims of cerebellar disease. The method of such

Fig. 12.



investigation is simple. With a plate of glass one centimetre thick and ruled in squares of half centimetre side, it is easy with the person to be investigated blindfolded and putting the plate successively in each of the three planes of space, to obtain a record if the person observed places one finger on one side and then endeavours to touch that point accurately with the other finger when it is carried vertically to the surface of the plate.* Inasmuch as each half of the body is

* A similar method has been used by Bloch in observations on the difference between the sense of muscles actively and passively moved. *See* "Comptes Rendus de la Société de Biologie," 1884, p. 31.

topographically a distinct organ, the plate must, in the investigation of the frontal planes, be placed opposite each half of the body respectively. Thus the average error of position can be deduced. It will be obvious that this method involves the exercise of two psychical processes : (1) The knowledge and memory of the probable whereabouts in space of a certain area of skin, *e.g.*, the finger-tip, and (2) the concurrent feeling experienced in the point touched. It is quite possible that these two processes find a different localisation in the cerebral hemisphere, but this is too large a question to enter upon now, and, moreover, the point immediately at issue is the coarser inter-relationship between the cerebrum and cerebellum respectively, which is revealed by the character or precision of the movement of the exploring finger. I would only say that I find that when the cerebellum is put out of gear the normal error which averages in the most favourable plane slightly less than one centimetre, is increased five or six fold, hence for the function of exploration of space as part of the basis of orientation, the cerebellum is clearly an essential organ.

So much for the general use of our sense of touch, and its value in the accurate co-ordination of muscular movements. We must now turn to a special use of sense impressions (mainly tactile) which the cerebellum receives from our lower limbs and trunk, and which it must receive in all completeness and accuracy for what Boyle called the admirable faculty of locomotion. We stand upright and look straightforward ; in so doing, were it not for the sense impressions arising in the soles of our feet and lower limbs, we have no knowledge of the ground we stand on unless we happen to have looked at it as we approach the spot. A good example of this is the way in which people whose gaze is interestedly directed horizontally forwards tread on the dresses and toes of their companions. Reference

to (Figure 6) shows the angle at which, with the visual axes parallel to the horizon, an object comes into view on the ground in front of the feet.*

Therefore our erect posture is an automatic act, depending for its successful performance on the sense of touch of the skin of the soles of our feet, on the pressure sensations of the joints, and tension sensations of the muscles of the lower limbs and trunk, on the integrity of the spinal marrow, and finally on the efficient receptivity of our cerebellum.

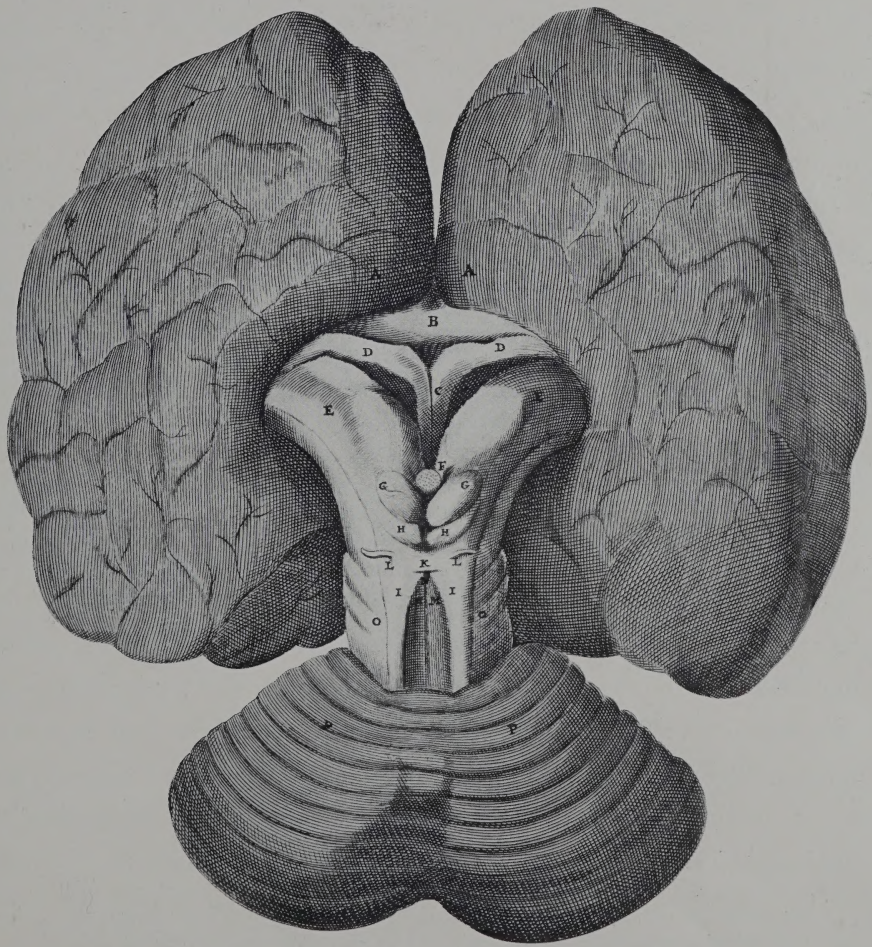
Now let us consider how these afferent sensations reach the cerebellum, and what part of that organ receives them after they have entered the spinal cord by the posterior roots and their collaterals. They enter the posterior horns of grey matter, and especially Clarke's column. From these stations they ascend the cord chiefly by the direct cerebellar tract, partly by Gowers' tract. Both paths end in the middle portion of the cerebellar cortex. It is therefore at least clear that the central part or vermis of the cerebellum is the special region which receives the necessary impressions for standing and for movements in space as regards the antero-posterior plane, *i.e.*, not merely translation of the whole body forwards horizontally, as in walking or running, but also bending of the body forwards or backwards, *i.e.*, rotation round a transverse axis passing through the centre of gravity.

This conclusion is finally established by the fact that lesions of this part of the cerebellum in man and animals causes falling forwards or backwards.

* I have found that the distance from the longitudinal axis of the body to the point where the margin of the visual field becomes clearly defined is frequently the same as the distance of the centre of gravity (marked by the central spot in the Diagram) of the whole body from the ground. I presume this is really only another way of stating the fact that the horizontal distance of the edge of the visual field from the base of the mid-frontal plane of the body necessarily varies with the length of the lower limbs.

FIG. 13.

A A Right and Left hemispheres of the cerebrum or great brain. B Corpus Callosum. C D Fornix. E Pulvinar of optic thalamus. F Pineal body. G G Anterior colliculus or corpus quadrigeminum. H H Posteri or colliculus orcorpus quadrigeminum. I I Superior cerebellar peduncle. K Commissure of fourth nerve. L L Fourth nerve. M M Posterior longitudinal bundle. O O On the side of the mesencephalon indicate the course partly of the pontine or middle peduncle and partly of Gower's spino-cerebellar tract. P P the lateral lobes of the cerebellum between which is shown the vermis.




Copy of figure III. of Willis's "Cerebri Anatome" (1682 Edition) reduced to two-thirds size, showing the relative proportions of the cerebellum and cerebrum. This drawing was in all probability one of those executed for Willis by Sir Christopher Wren.

We may therefore sum up this first part of our cerebellar localisation by calling the vermis region and the ascending cerebellar tracts of the spinal cord the spino-cerebellar mechanism, and recognising that its function is the provision of accuracy of locomotion and the automatic maintenance of the erect posture.* There remain, occupying each side of the cerebellum, the lateral lobes or hemispheres, as they are termed in man, in which species of animal they attain their greatest proportionate development.

These lateral lobes are connected by powerful bundles of fibres (forming the middle peduncle) to the grey nerve centres in the pons varolii (see figure 3), as it is called, after the anatomist who first correctly described it. (See Lower's letter, p. 9.)

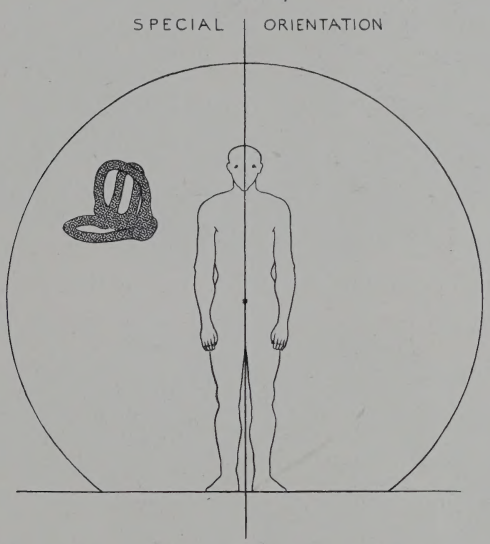
This ponto-cerebellar mechanism is in direct communication with the temporal lobe (from which issues a descending tract to the pons), and it is also of course in close connection with the kinæsthetic cortex, by the fact of the pyramidal tract giving off collaterals to the pontine nuclei as it passes through them.

We owe to Majendie our knowledge of the function of this portion of the cerebellar apparatus. That brilliant investigator proved that the middle peduncle of the cerebellum, Willis's "great half circular stem" of the cerebellum, was the nerve path whereby the muscular movements by means of which our body turns around its longitudinal axis were evoked, and considering, as I have already pointed out, that we are obliged by the necessities of life to be constantly rotating our bodies (if only through a few degrees at a time), and at any rate our head and eyes, the extreme importance to our existence of this part

* It must not be forgotten that though the spino-cerebellar mechanism is, in fact essential to the physiology of locomotion, the conscious activity of the cerebral pallium is equally essential, and that in the early stages of loss of consciousness, standing and locomotion soon fail.

of the cerebellar mechanism will be sufficiently obvious. I repeat that Willis had already noted the intimate connection between the pons and the cerebellum, and I will now also recall the fact, to be discussed presently more fully, that evidently his view, like that of Varolius, was that the eighth nerve,* as we now call it, sent fibres directly to the cerebellum.

FIG. 14.



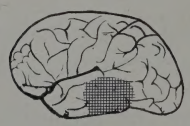

The semi-circular canals shown on a large scale by the figure are in their position when the optic axes are horizontal.

Everything that has been said so far converges to the conclusion which that great neurologist, Edinger, formulated a good many years ago, viz., that the cerebellum is essentially an organ for the reception of certain sensory impressions.

VI. *By Special Orientation.*—I wish now to enlarge on this matter so

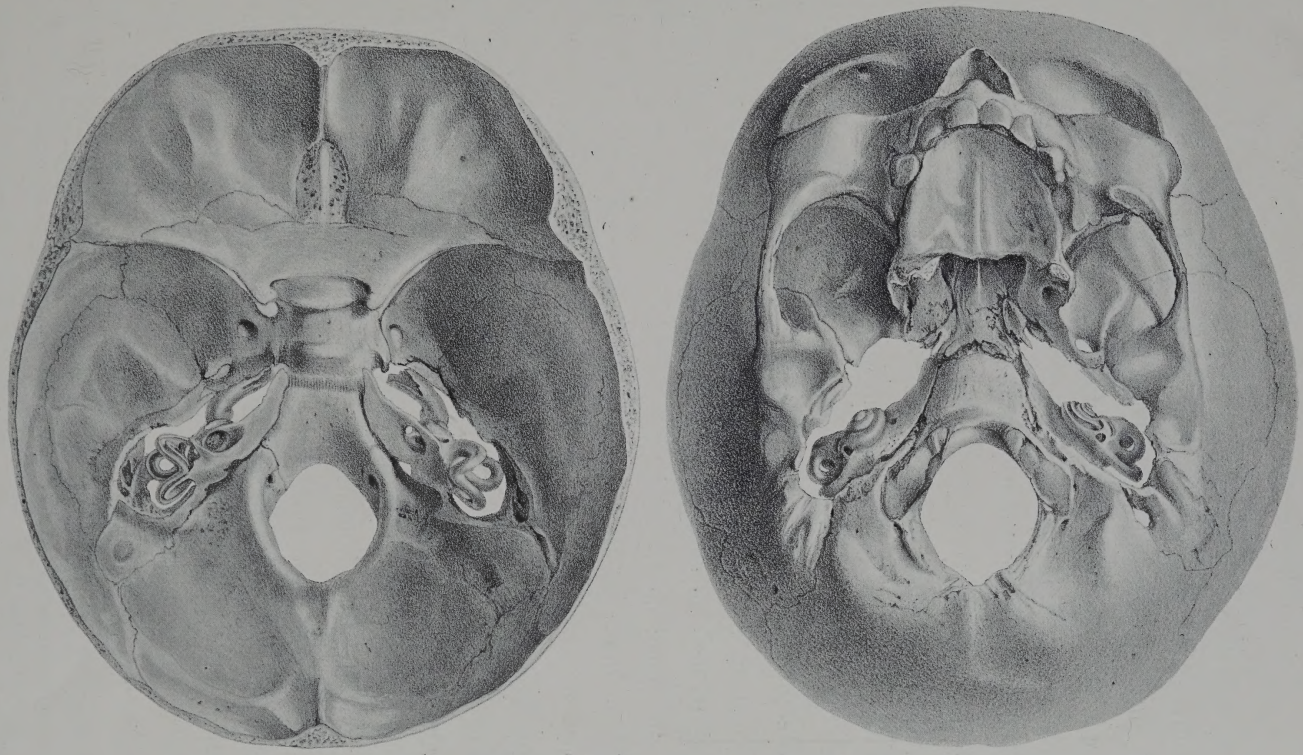
* Composed of its two parts, (*a*) auditory and (*b*) equilibratory or vestibular. The cerebellar relationship of the eighth nerve is now known to be with the vestibular or equilibratory portion.

far as what we may call our special sense of orientation is concerned, which sense is subserved by the vestibular portion of the eighth nerve. We know that, in addition to the avenues already discussed, the cerebrum and especially the cerebellum as recipient organs, are made aware of our position in space by a special apparatus, namely the semi-circular canals. These are situated in the internal ear, and the vestibular nerve coming from them was formerly regarded as an integral part of the eighth, or auditory nerve. It has long been contended by Edinger that the vestibular nerve is in direct communication with the cerebellum, and collateral communication has been anatomically proved by Ramon y Cajal. The canals are a closed system of tubes containing a watery fluid and furnished at their ends with a sensitive nerve apparatus capable of appreciating changes in the pressure of the fluid if the canal's position is altered. To this end the canals are arranged roughly in the three planes of space (see figures 14 and 15). Inclination of the head in any direction is recorded by the corresponding vertical canals according to the plane of movement, and the all-important rotation of the eyes, of the head, and later of the whole body is similarly made known to consciousness by the horizontal canals. Of course the nerve paths ascend from the nuclei of the vestibular nerve to the cerebral pallium by way of the optic thalamus, and,



following Mills, I suggest that present knowledge points to the temporal lobe being their first receptive station in the cerebral cortex. So much for our special orientation sense. The cerebellum as well as the cerebrum (Willis's true "metropolis" of thought), is clearly in part a direct recipient of vestibular impressions, and is thus subconsciously informed of the fact that our body, or at least our head, is moving in a given plane. I wish now to raise some further and perhaps more

FIG. 15.



Photographs of figures from Arnold's "Tabulæ Anatomicæ" of dissections of the skull seen from below and above showing the semicircular canals and cochlea.

novel considerations on the mutual shares taken by the cerebrum and cerebellum in the execution of our balancing and locomotory acts.

So far I have referred to the cerebellum as a receiving station, but of course no nerve centre exists without giving out the impulses which have been aroused or co-ordinated in its grey matter. Further, since we have seen that the correctness of our finer movements, and even of the way we walk, depends on the cerebellum, we must now see how the cerebellum influences the brain and the spinal cord.

In the first place, since the cerebellar cortex consists of the same structure throughout, the justifiable inference follows that the function of its different parts must be very similar. The most prominent element in its structure is the Purkinje cell. The axones of these cells go, according to different observers, to the brain, to the cerebellar nuclei, and to the spinal cord.

Up to the present time the cerebellum has customarily been considered as a whole by physiologists without recognising that it consists, anatomically, of two distinct elements: a superficial cortex or surface of grey matter remarkably homogeneous throughout, and smaller masses of grey matter internally which are called the cerebellar nuclei, and have a totally different structure. These are practically two, the roof nucleus and the dentate nucleus. Dr. R. H. Clarke and myself have for some years been engaged in an attempt to dissociate these two parts of the cerebellar structures in the carnivora and primates, and to finally test the opinion that the cortex of the cerebellum is in direct communication with the cerebrum above and the spinal cord below. Our anatomical work,* we think,

* Published in *Brain*, June, 1905. Since the publication of our paper the same subject has been investigated independently and very thoroughly by van Gehuchten, who employed a different species of animal, viz., rodents, and arrived at precisely the same conclusions.—"Le Nevraxe," July, 1905.

proves absolutely that this is not the case, but that the efferent axones of the cortical cells of the cerebellum end in the nuclei and neighbouring grey matter, and that though the cortex cerebelli receives impressions directly from the spinal cord, the pons, and the thalamus, it is only from the nuclei that efferent fibres go direct to these structures. This anatomical position coincides with the previous conclusion (Edinger) that the cerebellum is essentially an organ for the reception of sensory orientation impressions, and we would add its nuclei are the focal elements for collecting its outward-going impulses, *i.e.*, to the brain and spinal cord. Dr. Clarke and myself are now engaged in the further solution of this problem by investigating these two parts of the cerebellum both physiologically, and by the Galenical method of exclusion and anatomical degeneration. This latter method, which offers special difficulties, we have so far successfully met by means of electrolysis, and the results confirm the conclusions above stated.

On the interdependence of the two brains our work tends to show that the direction of the nerve currents between them is what might be morphologically expected, viz., that the cerebellum sends impulses cerebrum-wards by the superior peduncle, and that the cerebrum influences the small brain by the temporo-pontine bundle of Turck.

There is one branch of the subject which particularly affects the physiology of locomotion, but which I have left specially until now because of its individual interest, and that is the general influence of the cerebellum on the muscular system at large. Luciani, whose experimental work on the Cerebellum twelve years ago gave such a great impetus to our knowledge and to the study of this intricate subject of the precise connection between the cerebral pallium and

the cerebellum, proved that removal of the cerebellum as a whole, *i.e.*, cortex and nuclei together, evoked a considerable amount of muscular weakness on the same side as that on which the cerebellum had been removed. Consequently he assumed that the destruction of the cerebellum meant a loss of one of the sources of nerve energy to the muscles. This observation of Luciani's has, I consider, been absolutely established, and is a very valuable aid to clinical diagnosis, but the full explanation of the phenomenon will not be forthcoming until we have succeeded in differentiating the function of the cerebellar nuclei from that of the cortex. So, too, another important question awaits solution—I refer to the discovery by Risien Russell of the remarkable homolateral influence which the cerebellum (viewed as a whole) exerts on the reflex functions of the spinal cord. This, too, is a matter which is largely a question of differentiation of the functions of the nuclei from that of the cerebellar cortex, and with the cerebellar nuclei must be also determined the relative share taken by Deiter's nucleus and the other vestibular nuclei.

You may have expected me to discuss the theories of various philosophers as to the supposed psychical activities of the cerebellum imagined by Gall, or, before him, by Willis.

But it is a waste of time to discuss theories and hypotheses, and I would rather reply with Boyle: "Indeed these (things) need good proof to make a wary man believe so strange a thing."

It is in his spirit we should approach an objective study, and with that clear scientific principle before us, I must conclude this sketch in which I have endeavoured to show how the small brain or cerebellum works in perfect co-operation with the large brain and with the spinal cord, for if I may again quote Robert Boyle, to honour whose life's work this Lecture was instituted—

"I consider the body of a living man not as a rude heap of limbs and liquors, but as an engine consisting of several parts so set together that there is a strange and conspiring communication between them."

THE END.